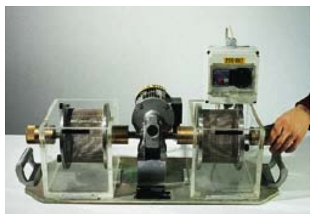
SLAKE DURABILITY

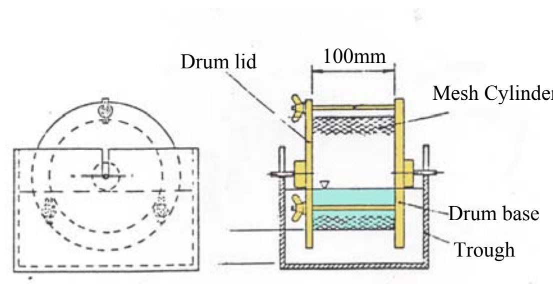
Changes in rock properties due to processes of chemical and mechanical breakdown (eg. exfoliation, hydration, solution, oxidation, abrasion etc.) can be very important in engineering applications. A good index test of rock degradability is the Slake Durability Index.

Apparatus :-

- **140mm diameter drum with 100mm long 2mm mesh walls.**
- **trough to contain drum + water**
- **motor drive (20rpm)**



SLAKE DURABILITY APPARATUS



SLAKE DURABILITY

Method

1. **Sample consisting of 10 spheroidal lumps each approx 50g is placed in the drum and weighed.**
2. **Drum is placed in trough filled with water at 20°C to a level just below drum axis and rotated at 20rpm for 10 minutes.**
3. **Drum is removed and material retained dried at 105°C**
4. **Cycle is repeated and the dried material retained after 2 cycles weighed.**

$$\text{SLAKE DURABILITY INDEX} = \frac{\text{Weight retained 2 cycles}}{\text{Initial weight}}$$

SLAKE DURABILITY CLASSIFICATION

DURABILITY	Cycle 1 (% retained)	Cycle 2. (% retained
Very High	>99	>98
High	98-99	95-98
Medium-High	95-98	85-95
Medium	85-95	60-85
Low	60-85	30-60
Very Low	<60	<30

SWELLING PRESSURE AND STRAIN

The Swelling pressure index is a measure of the pressure necessary to constrain at constant volume, an undisturbed rock specimen immersed in water. The apparatus used is similar to a soil consolidometer.

Swelling Pressure Index, I_{sp} = F/A

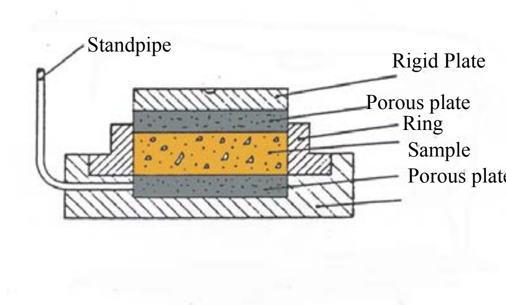
F = Max axial swelling Force
A = Cross sectional area of specimen.

The Swelling strain index is a measure of the axial swelling strain developed when a radially confined undisturbed rock specimen is immersed in water.

Swelling Strain Index, I_{ss} = d/L *100%

d = Max swelling displacement
L = Initial height of specimen

CONFINED SWELL TEST

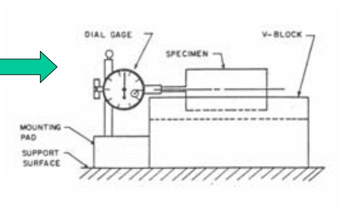


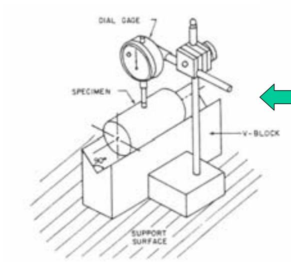
LABORATORY TESTING OF INTACT ROCK

SAMPLE PREPARATION

DRILLING → CUTTING → END GRINDING

End must be flat and perpendicular to core axis



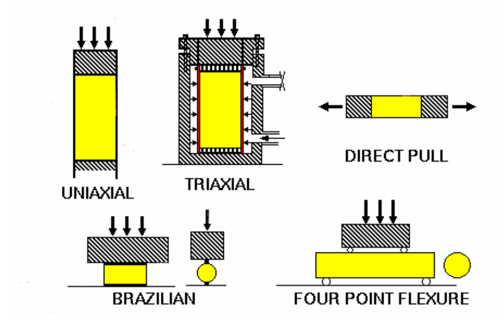


Core must be straight

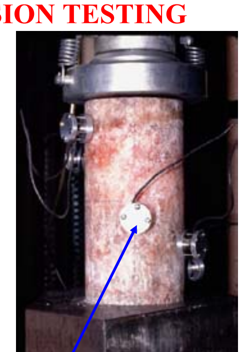
SAMPLE PREPARATION 2

METHODS OF TESTING

- Unconfined
- Confined



UNIAXIAL COMPRESSION TESTING

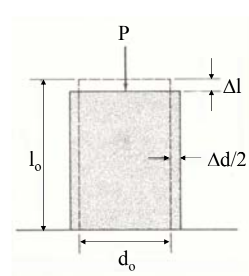


Strain Gauges bonded to specimen

$$Co = \frac{P}{A} = \frac{4P}{\pi d^2}$$

Acoustic emission transducers

AXIAL AND LATERAL STRAIN POISSON'S RATIO



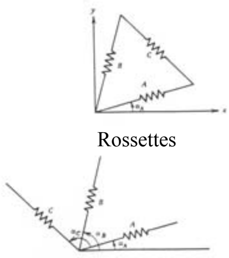
$$\varepsilon_{axial} = \frac{l_o - l}{l_o} = \frac{\Delta l}{l_o}$$

$$\varepsilon_{lateral} = \frac{d_o - d}{d_o} = \frac{\Delta d}{d_o}$$

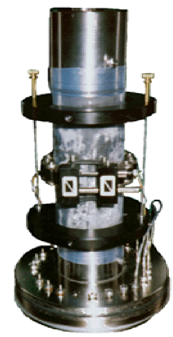
Poisson's ratio, ν,

$$\nu = \frac{-\varepsilon_{lat}}{\varepsilon_{axial}}$$

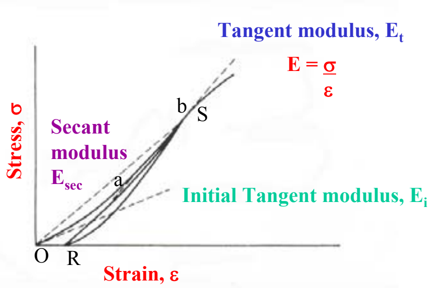
$$\varepsilon_{lat} = -\nu\varepsilon_{axial} = -\nu\varepsilon_1$$



STRAIN MEASUREMENT



ELASTIC MODULI



Volumetric Strain

For strains of several % of the volume change per unit volume, then the volumetric strain, ΔV/V is given by :-

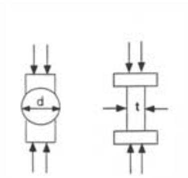
$$\frac{\Delta V}{V} = \varepsilon_{axial} + 2\varepsilon_{lat} \qquad = \varepsilon_1 + \varepsilon_2 + \varepsilon_3$$

As from $\varepsilon_{lat} = -\nu\varepsilon_{axial} = -\nu\varepsilon_1$

then $\varepsilon_2 = \varepsilon_3 = -\nu\varepsilon_1$ and

$$\frac{\Delta V}{V} = \varepsilon_1(1 - 2\nu)$$

BRASILIAN DISC

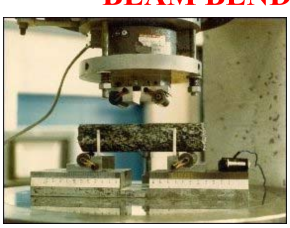


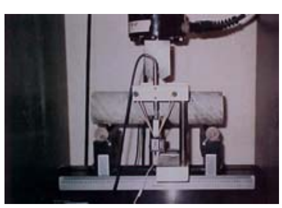
BRAZILIAN INDIRECT TENSILE TEST

- Core Disks usually have thickness (t): diameter (d) ratios of 0.5 - 0.25
- ends parallel and normal to the cylinder axis
- grinding ends for smoothness and flatness is not needed
- Arcuate platens are used to minimise crushing at the contacts
- Diametral loading is applied in increments or at constant strain rate to induce failure within 10 mins.
- Tensile stresses are generated normal to the cylinder axis and loading axis and parallel to the disk diameter
- T_{BR} = 1-10 x Direct Tensile Strength

$$T_{BR} = \frac{2P}{\pi d t}$$

BEAM BENDING TEST

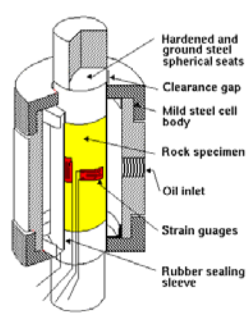




- 3 or 4 point loading
- L:D ratio > 4, end unprepared.
- T_{MR} = 1 to 10 x Direct Tensile Strength

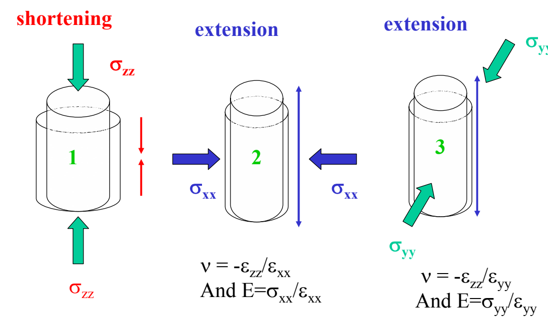
Fracture Toughness Test – modified to include slit in middle of core.

HOEK TRIAXIAL CELL



HOEK CELL

3 components of strain in the z. direction (similarly for x and y)



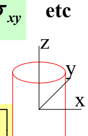
$$\varepsilon_{zz} = \sigma_{zz}/E \quad - \nu\sigma_{xx}/E \quad -\nu\sigma_{yy}/E$$

STRESS-STRAIN in 3D: ISOTROPIC ELASTICITY

$$\varepsilon_{zz} = \frac{1}{E}\left[\sigma_{zz}\right] - \nu\left(\sigma_{xx}+\sigma_{yy}\right)\Big] \qquad \varepsilon_{yy} = \frac{1}{E}\left[\sigma_{yy} - \nu\left(\sigma_{xx}+\sigma_{zz}\right)\right]$$

$$\varepsilon_{xx} = \frac{1}{E}\left[\sigma_{xx} - \nu\left(\sigma_{yy}+\sigma_{zz}\right)\right] \qquad \gamma_{xy} = \frac{1}{E}\left[2(1+\nu)\right] = \frac{1}{G}\sigma_{xy} \quad \text{etc}$$

Where G = Shear Modulus = $G = \dfrac{E}{2(1+\nu)}$



$$\begin{bmatrix}\varepsilon_{xx}\\ \varepsilon_{yy}\\ \varepsilon_{zz}\\ \gamma_{xy}\\ \gamma_{yz}\\ \gamma_{zx}\end{bmatrix} = \frac{1}{E}\begin{bmatrix}1 & -\nu & -\nu & 0 & 0 & 0\\ -\nu & 1 & -\nu & 0 & 0 & 0\\ -\nu & -\nu & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 2(1+\nu) & 0 & 0\\ 0 & 0 & 0 & 0 & 2(1+\nu) & 0\\ 0 & 0 & 0 & 0 & 0 & 2(1+\nu)\end{bmatrix}\begin{bmatrix}\sigma_{xx}\\ \sigma_{yy}\\ \sigma_{zz}\\ \sigma_{xy}\\ \sigma_{yz}\\ \sigma_{zx}\end{bmatrix}$$

NUMERICAL EXAMPLE

A cylindrical specimen of elastic isotropic rock was loaded in a triaxial cell with a confining pressure of $4MN/m^2$ and an axial stress of $33MN/m^2$. Strain gauges attached to the specimen indicated an axial strain of 850microstrains with a lateral (extensile) strain of –20microstrains. Calculate the Elastic Modulus,E, and Poisson's ratio,ν. (1microstrain = 10^{-6} and 1MN/m = 10^6 N/m)

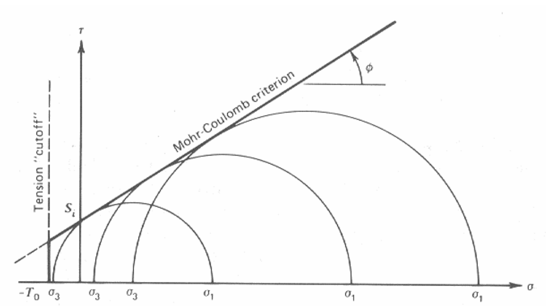
$$\varepsilon_{xx} = \frac{1}{E}\left[\sigma_{xx} - \nu\left(\sigma_{yy}+\sigma_{zz}\right)\right] \qquad -20\mu S = \frac{1}{E}\left[4 - \nu\left(33 \;\; +4\right)\right]$$

$$\varepsilon_{zz} = \frac{1}{E}\left[\sigma_{zz} - \nu\left(\sigma_{xx}+\sigma_{yy}\right)\right] \qquad 850\mu S = \frac{1}{E}\left[33 - \nu\left(4 \;\; +4\right)\right]$$

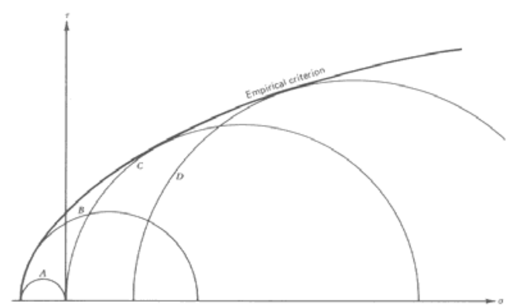
$$E = \frac{4-37\nu}{-20} \quad \text{and} \quad E = \frac{33-8\nu}{850} \qquad \text{Solve for } \underline{\nu = 0.128}$$

Substituting $E = \dfrac{33-8\nu}{850}$ $\quad = E = \dfrac{33-8(0.128)}{850}$ $\quad$ **E = 37.6GPa**

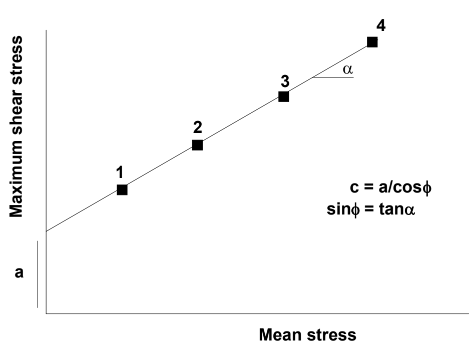
TRIAXIAL MOHR CIRCLE CONSTRUCTION FOR ROCK



ROCK FAILURE CRITERION



TRIAXIAL TEST: p-q plot

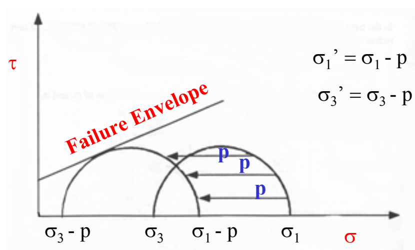


Representative Values for Shear Strength Intercept (S_i) and Angle of Internal Friction (ϕ) for Selected Rocks

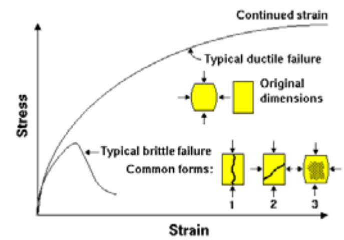
Description	Porosity (%)	S_i (MPa)	ϕ	Range of Confining Pressure (MPa)
Berea sandstone	18.2	27.2	27.8	0–200
Bartlesville sandstone		8.0	37.2	0–203
Pottsville sandstone	14.0	14.9	45.2	0–68.9
Repetto siltstone	5.6	34.7	32.1	0–200
Muddy shale	4.7	38.4	14.4	0–200
Stockton shale		0.34	22.0	0.8–4.1
Edmonton bentonitic shale (water content 30%)	44.0	0.3	7.5	0.1–3.1
Sioux quartzite		70.6	48.0	0–203
Texas slate; loaded				
30 degrees to cleavage		26.2	21.0	34.5–276
90 degrees to cleavage		70.3	26.9	34.5–276
Georgia marble	0.3	21.2	25.3	5.6–68.9
Wolf Camp limestone		23.6	34.8	0–203
Indiana limestone	19.4	6.72	42.0	0–9.6
Hasmark dolomite	3.5	22.8	35.5	0.8–5.9
Chalk	40.0	0	31.5	10–90
Blaine anhydrite		43.4	29.4	0–203
Inada biotite granite	0.4	55.2	47.7	0.1–98
Stone Mountain granite	0.2	55.1	51.0	0–68.9
Nevada Test Site basalt	4.6	66.2	31.0	3.4–34.5
Schistose gneiss				
90 degrees to schistocity	0.5	46.9	28.0	0–69
30 degrees to schistocity	1.9	14.8	27.6	0–69

ROCK SHEAR STRENGTH INTERCEPT. S_i and ANGLE OF FRICTION, ϕ.

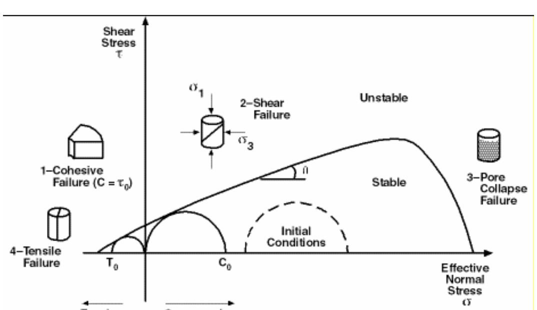
INFLUENCE OF PORE WATER PRESSURE



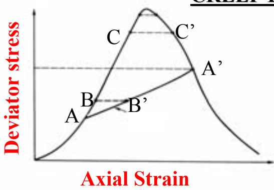
ROCK BEHAVIOUR



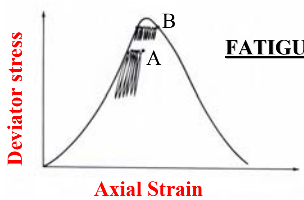
FAILURE CRITERION



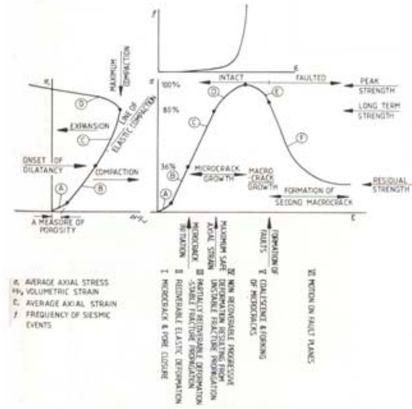
CREEP BEHAVIOR

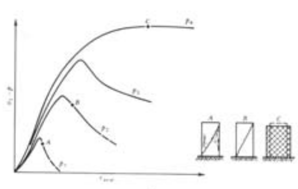


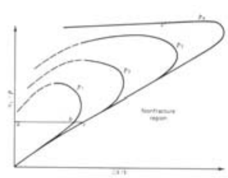
FATIGUE

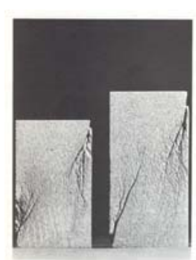


THE FAILURE PROCESS









Unconfined Compressive Strength (q_u) and Ratio of Compressive to Indirect Tensile Strength (q_u/T_0) for Specimens of Representative Rocks

Description[a]	q_u MPa	q_u psi	q_u/T_0[b]
Berea sandstone	73.8	10,700	63.0
Navajo sandstone	214.0	31,030	26.3
Tensleep sandstone	72.4	10,500	
Hackensack siltstone	122.7	17,800	41.5
Monticello Dam s.s. (greywacke)	79.3	11,500	
Solenhofen limestone	245.0	35,500	61.3
Bedford limestone	51.0	7,400	32.3
Tavernalle limestone	97.9	14,200	25.0
Oneota dolomite	86.9	12,600	19.7
Lockport dolomite	90.3	13,100	29.8
Flaming Gorge shale	35.2	5,100	167.6
Micaceous shale	75.2	10,900	36.3
Dworshak Dam gneiss			
45° to foliation	162.0	23,500	23.5
Quartz mica schist ⊥ schistocity	55.2	8,000	100.4
Baraboo quartzite	320.0	46,400	29.1
Taconic marble	62.0	8,990	53.0
Cherokee marble	66.9	9,700	37.4
Nevada Test Site granite	141.1	20,500	12.1
Pikes Peak granite	226.0	32,800	19.0
Cedar City tonalite	101.5	14,700	15.9
Palisades diabase	241.0	34,950	21.1
Nevada Test Site basalt	148.0	21,500	11.3
John Day basalt	355.0	51,500	24.5
Nevada Test Site tuff	11.3	1,650	10.0

UNCONFINED COMPRESSIVE AND TENSILE STRENGTH